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Technical Report 60

HERBICIDAL CONTROL OF SELECTED ALIEN PLANT SPECIES IN HAWAII VOLCANOES NATIONAL PARK: A PRELIMINARY REPORT

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ABSTRACT

Herbicide tests were conducted between April 1984 and June 1986 on 7 species of alien plants which have been classified as current or potential threats to native ecosystems within Hawaii Volcanoes National Park. The study was designed to be an initial series of tests to develop effective treatment techniques and to gather some baseline information on the effects of herbicides on native flora.

Highly effective treatments were found for Russian olive (*Linociera ligustrina*) (TORDON RTU on cut stumps) and for both species of silky oak (*Grevillea banksii* and *G. robusta*) (2.5% GARLON 4 in diesel oil applied in continuous frill cuts). No hazards to native plants were detected. Treatments for glorybush (*Tibouchina urvilleana*) (20% GARLON 4 in diesel oil on cut stumps) and yellow Himalayan raspberry (*Rubus ellipticus*) (40% GARLON 4 in a foliar drizzle spray and 20% TORDON 22K in water on cut stumps) appeared effective: however, further testing is necessary to refine treatments, verify results, and further assess potential harm to native plant species. Kahili ginger (*Hedychium gardnerianum*) was effectively controlled with TORDON 10K pellets; however, further testing is warranted for several reasons. A 2% foliar spray of ROUNDUP in water was not completely effective on blackberry (*Rubus argutus*), but it did provide a good measure of control and would be useful in selected situations. Further testing on blackberry is necessary to increase treatment effectiveness and to evaluate other treatments.

We recommend continued modest emphasis on herbicide research in Hawai'i's native ecosystems to: increase treatment effectiveness on these and other problem plants: evaluate the effects of retreatment regimes: increase knowledge of hazards to native plants and animals: broaden the range of safe chemical tools needed to integrate herbicides with other methods of ecosystem restoration: monitor operational herbicide programs for efficacy and cost effectiveness: increase long-term monitoring of treatment effects in selected areas; and determine and enhance responsible management programs in near-native ecosystems.

INTRODUCTION

The Natural Resources Management Plan (Hawaii Volcanoes National Park 1986) for Hawaii Volcanoes National Park (HAVO) addresses the problem of alien plant control as follows:

> The introduction, spread, and persistence of exotic plants present the most serious, long-term threat to Park ecosystems.... They displace native vegetation and many can form monospecific stands or vegetation layers.... Their potential for disrupting native plant communities is indicated by their aggressiveness [and/or] their taxonomic affinities to taxa characteristically aggressive in local environments [elsewhere].... The history of population dynamics in other tropical environments indicates that populations of highly aggressive and disruptive species may occur at very low numbers for many years prior to sudden expansion.... Efficiency of [control] effort is especially critical because of funding and manpower limitations, the seriousness of the threat of exotic plants to the native biota, the explosive expansion of some weed species, and the rapid growth of sprouts and seedlings in a tropical environment.... Initial work indicates that long-term monitoring and research are required to develop treatment methods which are both effective and ecologically sound.

In response to the threat of alien plants identified in the Natural Resources Management Plan of HAVO, the National Park Service (NPS) in conjunction with the Cooperative National Park Resources Studies Unit of the University of Hawaii (CPSU/UH) initiated a broad-scale research program to develop biological, mechanical, and chemical controls for alien plants. In the past, control efforts on alien plant species in the Park were largely conducted on a trial and error basis.

Of the approximately 400 alien plant species naturalized in the Park, 50 present the greatest threats to native ecosystem processes and have been targeted for control. These 50 species have been prioritized by the HAVO Resource Management Division (RM) according to the magnitude of the threat they pose, the estimated cost and effort of control, and potentially successful control methods (Hawaii Volcanoes National Park 1984).

The purpose of this report is to summarize information on herbicidal tests conducted from 1984-1986 on 7 species classified in one of 3 categories by RM: Category I (highly localized, potentially disruptive species); Category II (established, disruptive species); or Category IV (candidate species for localized control). Category III includes candidate species for biological control and is not covered in this report.

SPECIES OF CONCERN

Kahili ginger, *Hedychium gardnerianum* Roscoe, native to the Himalayas, is considered by horticulturists as one of the most desirable garden plants in Hawai'i. It is a cold-tolerant species found in its native habitat at altitudes to 2,500 m. Open inflorescences, about 25 cm in length, develop at the tips of the stems, which can themselves reach over 2 m in height (Neal 1965). Although somewhat localized within the Park, kahili ginger is heavily infesting more than 500 ha and is a serious threat to native rain forests. A very aggressive, shade-tolerant plant, it has the ability to establish itself under dense canopies and has become naturalized in the 'ohi'a (*Metrosideros polymorpha* Gaud.) forests in and around HAVO. Kahili ginger can invade and establish itself in intact native rain forest habitat, where it can form dense monotypic stands 2-3 m in height and displace native understory vegetation. Kahili ginger reproduces both vegetatively, with a massive rhizome system, and sexually, through dispersal of seeds, although the first is more common.

Russian olive (*Linociera ligustrina* Sw.), a relatively recent pest in HAVO, is found on over 6,000 ha in the Ainahou Ranch area in the Park. Its current elevational range in the Park is between 500-1,000 m (J.T. Tunison, pers. comm.). The infestation has expanded rapidly since the removal of cattle (*Bos taurus*) from the Ainahou area in the early 1970's. Trees in excess of 5 m in height have been observed, and it is believed that Russian olive will shade out native species. It can form dense thickets which disrupt natural ecological processes such as the regeneration of native flora. Currently, there is some disagreement as to taxonomic classification, and a literature search has not revealed information on origin, phenology, or introduction to Hawai'i. Russian olive is used frequently as a landscape plant, especially as a windbreak hedge. It reproduces by seedlings which are often present under the parent tree, sometimes in excess of 1,200 individuals/m^2 (Santos, unpubl. data).

Two species of silky oak (*Grevillea robusta* (A. Cunnin) R. Br. and *G. banksii* R. Br.) are currently invading the Park via the southwestern Ka'u boundary. *Grevillea robusta*, a robust, partly deciduous tree native to Australia, was introduced to the State of Hawai'i for reforestation purposes in 1938. It is found in a wide variety of habitats and at altitudes from sea level to over 1,300 m elevation. A fast-growing tree, it can reach heights in excess of 30 m. It is drought tolerant, and its wind-dispersed, winged seeds have the ability to germinate in bare, rocky soil (Neal 1965).

Grevillea banksii, also native to Australia, is a small tree up to 6 m high, with large red flower spikes. Poisonous flowers and fruit cause a skin reaction (Haselwood and Motter 1984). This tree was officially designated a noxious weed by the Hawai'i Department of Agriculture in 1978 (Regulation NW 10, updated by Title 4, Chapter 68 Administrative Rules, 1981). It reproduces by seeds.

Both species of Grevillea are aggressive, drought-tolerant, have the ability to establish themselves in little or no soil, and may form dense, monotypic stands, which may gradually displace dry forest and scrub in HAVO.

Florida blackberry (Rubus arsutus Link) is found throughout the Park, at elevations between 700 and 2,000 m (Smith 1985). It can form thorny, brambled thickets up to 3 m tall. It is equally adapted to heavy shade and full sun, and to rain forests, submontane forests, and dry grasslands. It spreads both vegetatively through aerial shoot runners and root suckers, and sexually through heavily seeded berries. Also called R. lucidus Rydb., R. recurvans Blanchard, R. persistans Rydb., and R. penetrans Bailey, Florida blackberry was introduced to Hawai'i in 1894 (Haselwood and Motter 1984). By 1962, it had infested 17,565 ha on O'ahu, Kaua'i, Maui, and Hawai'i at altitudes of 600 m or higher. This blackberry is possibly a native of Florida; however, the taxonomy is uncertain. St. John (1973) considered Florida blackberry a cultigen rather than any of the above species per se. Areas which are heavily infested are quite impenetrable due to the tangling growth habit and the sharp thorns on the branches and leaves. The fruits, which are clusters of drupelets, are used raw or cooked (Neal 1965) but are of no commercial value in Hawai'i.

Blackberry has no forage value and has been known to cause serious injury to cattle when the canes become lodged in the nasal passages and cannot be expelled. The State of Hawai'i has offically classified R. arsutus as a noxious weed.

To date, the State of Hawaii has released 4 insects in an attempt to control R. argutus biologically (Gardner and Davis 1982). Partial success has been reported on the islands of Maui and Kaua'i (Hosaka 1945). Work is continuing to find more effective agents.

Yellow Himalayan raspberry (Rubus ellipticus Sm.) is currently widespread throughout the wetter sections of Kilauea Volcano, especially in areas disturbed by either man or feral pigs (Sus scrofa). Yellow raspberry is spread by underground root sprouts and by seeds which are probably dispersed by alien and native frugivorous birds (Smith 1985) and rats (C.P. Stone, unpubl. data). The current elevational range of R. ellipticus in Hawai'i is between 700 and 1,700 m. Himalayan yellow raspberry is a threat to the Ola'a Tract of HAVO (Jacobi and Warshauer 1975). This noxious, sprawling bramble has sharp spines 2-3 cm in length, can reach a height of 3 m or more, and can establish itself on the ground or epiphytically, where it grows through and over the tree fern (<u>Cibotium</u> spp.) understory. <u>Rubus ellipticus</u> is well adapted to the full sun of open canopy forests or pastures, as well as the deep shade of rain forests.

Glorybush or lasiandra (<u>Tibouchina urvilleana</u> (DC.) Cogn. in DC.), a native of Brazil, is a member of the melastome family. It was introduced to Hawai'i as an ornamental, probably for its brillant purple, velvety flowers, 8 cm in diameter, which are borne either singly or in clusters on branch tips (Neal 1965). It is currently found in wetter habitats on O'ahu, Kaua'i and Hawai'i between 200-1,700 m elevation. Thickets can reach a height of 4 m. This woody tree-shrub is found in disjunct populations in HAVO at approximately 1,200 m elevation. However, just outside the Park's eastern boundary, glorybush has invaded native rain forests and formed large, dense monotypic stands to 5 m in height or more. Glorybush spreads by both root and shoot runners and possibly by seeds.

Photos of alien plant species used in herbicide tests may be found in Appendix A.

HERBICIDES TESTED

Herbicides used in this series of tests and currently approved for limited use and testing within Park boundaries include:

AMITROL T Herbicide (Union Carbide Agricultural Products Company, Inc., P.O. Box 12014, T.W. Alexander Dr., Research Triangle Park, N.C. 27709): (amitrole + ammonium thiocyanate at 2 lbs. active ingredient (ai)/gal.); EPA Registration No. 264-135-ZA. Amitrole is a non-selective systemic herbicide used to control both grasses and broadleafed species.

GARLON 4 Herbicide (The Dow Chemical Company, Agricultural Center, P.O. Box 1706, Midland, Mich. 48640): (the ester formulation of triclopyr at 4 lbs. acid equivalent (ae)/gal.); EPA Registration No. 464-544. Triclopyr is a selective, systemic herbicide used for control of woody species.

ROUNDUP Herbicide (Monsanto Company, Agricultural Products, St. Louis, Mo. 63167): (glyphosate as the amine salt formulation at 3 lbs. ae/gal.); EPA Registration No. 524-308-AA. Roundup is a non-selective systemic herbicide.

TORDON 10K Pellets Herbicide (Dow Chemical Co.): (picloram as the potassium salt at 10% ae/lb.); EPA Registration No. 464-320. Picloram is a persistent, non-selective systemic herbicide used primarily to control broadleafed and woody species.

TORDON 22K Herbicide (Dow Chemical): (picloram as the potassium salt at 2 lbs. ae/gal.); EPA Registration No. 464-323.

TORDON RTU (Dow Chemical): (picloram + 2,4-D as amine salts at 3% and 11.2% ae/gal.); EPA Registration No. 464-510.

Treatment techniques used in these tests were derived from practical approaches to field application with regard to lifeform of target species, applicator safety, cost and energy efficiency, expected residual activity of herbicide and toxicity to non-target native plant species, Techniques will be described for tests of particular chemicals on each target species.

DISCLAIMER

Reference to a company or product name does not imply approval or recommendation of that product by the Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, or the National Park Service to the exclusion of others that may be suitable. It is also acknowledged that some of the treatments tested are experimental and do not conform to labeled usages. Treatment recommendations which are not in accordance with the label are subject to approval of the manufacturer.

RHIZOME TREATMENTS FOR KAHILI GINGER

MATERIALS AND METHODS

Sixty clumps of kahili ginger, ranging in size from 0.25-1 m^2 (rhizome clump diameter) were chosen from populations in a mixed understory wet 'ohi'a forest community near the Hawaii Field Research Center and from an area east of Thurston Lava Tube at HAVO. Elevation at test sites was 1,200 m, with mean annual rainfall and temperature of 3,300 mm and 17° C.

Treatments tested included: undiluted GARLON 4, TORDON 22K, AMITROL T, ROUNDUP, and TORDON RTU injected into the rhizomes via the Maujet Micro-Injection System (J.J. Maujet Co., Inc. P.O. Box 3422, Burbank, Calif. 91504). Maujet injectors were included in the treatments because previous studies by Johnson et al. (1984) showed them to be an effective way of introducing insecticide into the vascular systems of pine trees. We hoped that injectors could provide a highly target-specific technique which would be safe for applicators and surrounding native vegetation. Topical rhizome sprays of GARLON 4, AMITROL T, TORDON 22K, and ROUNDUP in a water carrier at 5% concentration volume/volume (v/v); and TORDON 10K Pellets at 4 kg ae/ha were also tested. A non-herbicidal treatment which consisted of removing all topgrowth followed by removal of all regrowth at 6-week intervals was also conducted. The interval was determined from observations of the time from bud emergence to the maturing of the first emerging leaf. P. Motooka (Extension

Specialist in Weed Science, College of Tropical Agriculture and Human Resources, University of Hawaii/Manoa) believed that up to this time the new shoot is producing more energy (through photosynthesis) than it is using for growth (P. Motooka, pers. comm.). The purpose of the continual regrowth removal treatment was to attempt to deplete the rhizome colony of its energy reserve.

All treatments were directed at rhizome clumps, as tests by Gardner (1984) indicated that foliar and basal sprays were either ineffective or effective only at rates injurious to surrounding native vegetation. All topgrowth was removed from each clump with a cane knife immediately prior to chemical treatment. For the Maujet treatments, 4 injector capsules, each filled with 5 ml of the appropriate herbicide, were inserted into each clump at evenly spaced intervals around the outer edge. The recommended method of inserting the injectors into woody trees was not applicable on the soft, succulent tissue of the ginger rhizomes; therefore, the method was modified by inserting the injector tubes into rhizomes by hand and using a pair of vice-grip pliers to hold the tube at the proper depth while the capsule was inserted onto the tube using a rubber mallet. The Maujet injection treatment is illustrated in Appendix B.

TORDON pellets were used only at the Thurston site. Two techniques were tested, one in which the pellets were evenly distributed over the surface of the clump, and the other in which pellets were dropped into a 3-cm diameter hole which had been augered into the center of the clump to soil depth.

In the topical spray treatments, the herbicides were sprayed to wet from 500-ml plastic trigger spray bottles onto the portions of rhizomes visible above ground (after removal of the vegetation).

All treatments were applied under partially cloudy but dry conditions on September 26, 1984. Monitoring of the 60 ginger plots was conducted at monthly intervals for a period of one year, during which time rhizome vigor as well as presence or absence of resprouts was noted. Non-target native species which occurred within a 1-m radius of each treated rhizome colony were observed for possible reactions to the treatments. Responses were rated into 3 vigor categories as follows:

+ = increase in vigor from pretreatment condition (i.e., less chlorosis, new growth, increased flushing);
0 = no change from pretreatment condition;
- = decrease in vigor from pretreatment condition.

Ginger responses to treatment were evaluated with numerical categories as follows:

0 = no apparent effect, healthy resprouting, growth normal;

1 = < 25% rhizome death, resprouts with light abnormalities (chlorosis);
2 = 50% rhizome death, moderate resprouting, abnormalities more severe (deformities);
3 = 75% rhizome death, light resprouting, low vigor, leaf distortions, stunting:
4 = 100% rhizome death, no resprouting.

RESULTS AND DISCUSSION

Among ginger plots treated with undiluted herbicides injected into the rhizomes, only the AMITROL T and TORDON 22K treatments showed significant control of ginger (Table 1). With the TORDON 22K treatments, no resprouts were observed on any of the 5 clumps during the study period. At one year, rhizomes were decayed and control was 100%. With the AMITROL T treatments, clumps resprouted with severely chlorotic shoots. The shoots gradually declined in vigor, and at one year both shoots and rhizomes were in advanced decay. All visible portions of the rhizomes appeared dead at one year, and control effectiveness was rated at 100%. Treatments with the other injected herbicides showed considerably less control of ginger. Results demonstrated that while GARLON 4, ROUNDUP and TORDON RTU suppressed regrowth for up to 8 months, clumps were producing apparently healthy regrowth at one year (Table 1).

Among the treatments in which rhizomes were sprayed, TORDON 22K and AMITROL T produced only partial control. The TORDON-treated clumps produced distorted resprouts with twisted shoots and puckered leaves. In AMITROL T-treated clumps, resprouts were severely chlorotic and growth was retarded. Many of the chlorotic shoots declined and eventually died. Rhizome death was 25-50% with both TORDON 22K and AMITROL T treatments. Healthy resprouts were observed on surviving rhizomes of both treatments at one year.

The 2 methods of applying TORDON pellets (surface and auger) differed in effectiveness, with greater control of ginger achieved from the pellets broadcast evenly over the exposed rhizome surface. Following this treatment, decay of the rhizome began within 2 months. One small, distorted shoot was recorded on a single clump at 8 months. The shoot was stunted and reached a height of only 5 cm before both the shoot and associated rhizome died at 9 months. Control was 100% at one year.

When TORDON pellets were dropped into augered holes in rhizomes, rhizome death was recorded at 50-75% at 6 months. However, after 7 months, resprouting was noted on the distal edges of all the clumps, and sprouts were vigorous and apparently healthy. GARLON 4 and ROUNDUP rhizome sprays were ineffective in controlling kahili ginger.

The non-chemical treatment of continuous topgrowth removal failed to provide any sustained control of ginger.

Table 1. Response of kahili ginger (Hedychium gardnerianum) to herbicide treatment and removal of regrowth at 6-week intervals thereafter in Hawaii Volcanoes National Park, 1984-1985. (Numbers in table represent plant response category means of individuals treated in each test.)

Treatment*	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
CONTROL	0	0	0	0	0	0	0	0	0	0	0	0
GARLON 4												
100% Maujet	2.8	2.8	2.0	1.8	2.2	2.0	1.4	2.0	1.4	1.0	1.0	0.8
5% Rhizome	2.8	3.0	2.6	1.4	1.4	0.4	0.4	0.4	0.2	0.2	0.2	0
TORDON 22K												
100% Maujet	2.8	3.0	4.0	3.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
5% Rhizome	3.0	2.8	3.6	2.6	3.8	3.2	3.8	3.6	3.2	2.6	2.8	2.4
ROUNDUP												
100% Maujet	3.0	2.2	1.0	0	0.8	0.2	0	0	0	0.2	0	0
5% Rhizome	3.0	3.0	1.4	1.0	1.4	1.4	1.0	0.2	0	0	0	0
AMITROL T												
100% Maujet	3.0	3.0	3.0	2.8	3.6	3.8	4.0	3.8	3.6	4.0	4.0	4.0
5% Rhizome	3.0	3.0	2.2	2.2	2.6	2.6	2.8	2.6	2.4	2.8	2.8	2.8
TORDON RTU 100% Maujet	3.0	2.8	3.0	2.2	2.8	2.6	2.4	2.2	1.0	1.0	1.0	0.6
TORDON 10K PELLETS												
4 kg ae/ha Augered	2.2	2.8	3.0	3.0	3.0	3.0	3.0	2.6	2.2	2.2	2.0	2.0
4 kg ae/ha Surface	2.4	3.0	3.0	3.0	4.0	4.0	4.0	3.8	3.8	4.0	4.0	4.0
TOPGROWTH REMOVAL	0	0	0	0	0	0	0	0	0	0	0	0

*n = 5 clumps/treatment

Plant response categories:

0 = no effect, healthy resprouting, growth normal
1 = < 25% rhizome death, resprouts with light abnormalities (chlorosis)
2 = 50% rhizome death, moderate resprouting, abnormalities more severe (deformities)
3 = 75% rhizome death, light resprouting, low vigor, leaf distortions, stunting
4 = 100% rhizome death, no resprouting

The 5 plots of this treatment each produced abundant, vigorous and apparently healthy resprouts throughout the monitoring period. Six to 12 resprouts were removed from each clump at each cutting interval. After one year there was no decrease in resprout or rhizome vigor.

EFFECTS ON NON-TARGET NATIVE SPECIES

Effects on non-target species varied widely (Table 2), apparently as a result of herbicide used, amount of active ingredient applied per plot, and treatment technique. Proximity of the native plant to actual treatment location and different sensitivities to chemicals may also have affected results.

The injected TORDON 22K treatment was most significantly damaging to native vegetation within a l-m radius of treated clumps. All pilo (Coprosma ochracea Oliver), wawae'iole (Lycopodium cernuum L.), and 'ohi'a within the area, which included seedlings and mature individuals, were killed or showed signs of necrosis, stunting, or aberrant growth.

The only casualty in the injected AMITROL T treatment was one pa'iniu (Astelia menziesiana Sm.) individual growing on top of a treated clump. This plant exhibited the typical AMITROL T- induced symptoms of severe chlorosis prior to death. Other Astelia located within 1 m from the treatment were unaffected.

TORDON 10K pellets heavily impacted an individual Clermontia parviflora Gaud. ex Gray 75 cm in height growing 60 cm downslope from one of the broadcast-treated ginger clumps. Vigor in this individual declined from moderate (pretreatment) to dead (4 months after treatment). Similarly, an individual kolea (Myrsine lessertiana A. DC.) sapling 70 cm in height, located 60 mm from an augered-pellet plot, declined from excellent pretreatment vigor to poor vigor at 12 months. One kolea seedling 90 cm from a broadcast-pellet plot remained in good vigor during the study period. No adverse effects were observed on non-target native species associated with any of the remaining treatments for ginger.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

While the injected TORDON 22K treatment effectively controlled kahili ginger, it cannot be recommended because of the heavy impact it had on native flora. The injected AMITROL T treatment was also very effective, with only minor effects on non-target plant species; however, the high cost of this treatment (equipment and labor) may preclude its use on a widescale basis. Broadcasted TORDON 10K pellets were an effective and relatively economical treatment and, in general, had only minor effects on the native flora in this test. However, picloram, the active ingredient in TORDON, is a persistent chemical which was shown (in this test) to be lethal to native species when present in sufficient concentrations. Tests in temperate climates have shown that

Table 2. Effects of chemical treatments of *Hedychium gardnerianum* on native vegetation within 1 m of treated c[illegible] (see key)

SPECIES	CONTROL	GARLON 4 100%	GARLON 4 5%	ROUNDUP 100%	ROUNDUP 5%	AMITROL T 100%	AMITROL T 5%	TORDON 22K 100%	TORDON 22K 5%	TORDON 10K B'cast	TORDON 10K Augured	TORDON RTU Maujet
Astelia menziesiana (pa'iniu)		Ø1			ØZ	-0/Z						ØZ
Cheirodendron trigynum ('olapa)									0/1	+/1	0/1	
Cibotium glaucum (hapu'u/pulu)				0/1			0/1	0/1	0/1	0/1	0/1	
Clermontia parviflora ('oha)										-/1		
Coprosma sp. (pilo)	0/2	0/5	0/1	+/4	0/2	+/2*	0/1	-/1	0/1	0/7*	0/4*	/1
Hedyotis centranthoides			0/1									
Ilex anomala (kawa'u)									Ø1	+/2*	0/4	
Isachne distichophylla (ohe)						0/1				0/1	0/1	
Lycopodium cernuum (wawae'iole)		-/1						-/1				0/1
Machaerina angustifolia ('uki)									+/1	0/1		
Metrosideros polymorpha ('ohi'a)	0/2*	Ø5	/Z	0/4	Ø2	0/1		-/-	0/4	+/4	+/6	+/4
Myrsine lessertiana (kolea)				0/1			+/2	[illegible]		0/1	-/1	
Sadleria ('ama'uma'u)	+/1				Ø1		0/1	0/1		+/1	-/4	+2
Vaccinium spp. ('ohelo)	0/2	ØZ				0/1					0/1*	

Key:

vigor rating/# individuals (* = seedlings):

\+ = increase in vigor from pretreatment condition
0 = no change from pretreatment condition
\- = decrease in vigor from pretreatment condition

picloram retains soil residual activity (the herbicide in an active state) for at least one year (4 kg ae/ha rate), with sub-herbicidal residues present for at least 2.5 years (1 and 4 kg ae/ha rate) (Anderson 1983). It is believed (P. Motooka, pers. comm.) that with high rainfall, high organic matter in the soil, and microbial activity which occurs in the areas where kahili ginger is found, the residual activity of picloram is decreased: however, the degree of reduced activity is unknown. High rainfall may also increase the potential threat to native species, however, as picloram is water soluble and readily transported to other areas in surface runoff and/or in soil solution. Further research is definitely required to address concerns about persistence and mobility.

We recommend that TORDON 10K pellets not be used where water runoff is a problem and where rare plant species are present, until the degree of threat of this chemical to native species has been better established. More information on TORDON treatments in areas where ginger is less abundant and native plants more abundant is desirable, since application rates per unit area can be lower with the same result, i.e. removal of ginger. Since plot and sample sizes in this test were small and ginger densities high, it is difficult to generalize what effects TORDON 10K pellets might have on forest ecosystems on a large-scale basis. Therefore, tests with increased plot and sample sizes and lower ginger densities are necessary to determine treatment effectiveness and impacts on native species under these conditions. Monitoring should be long term, for target as well as non-target species, as picloram may persist in the soil for years. Long-term monitoring is necessary to evaluate effects on some of the larger, more slowly growing woody components of native forest systems ('ohi'a, pilo, etc.), which may not show symptoms for a year or more. The effects of picloram on the native microfauna are at present unknown, and that situation should be addressed: however, the cost may be prohibitive.

AMITROL T also appears promising as a control for kahili ginger if effective application techniques and concentrations can be found. Additional testing of this herbicide and other herbicides which are less threatening to native ecosystems than TORDON is warranted.

CUT-STUMP TREATMENTS ON RUSSIAN OLIVE

MATERIALS AND METHODS

Three hundred fifty Russian olive shrubs were chosen from a healthy population in a dry, very scattered 'ohi'a forest located in the Ainahou Ranch area of HAVO. The approximate elevation of the Ainahou area is 835 m and the mean annual rainfall and temperature are 1,955 mm and 19° C.

Prior to selection, basal stem diameter measurements were taken from 270 Russian olive shrubs at the test site to establish the size range and distribution of the population. For classification purposes, only the largest stem was measured on shrubs with basitonic (multi-trunked) branching. The olive shrubs were then grouped into 5 size classes based on the diameter of the largest stem: 3-5 cm, 5.1-7 cm, 7.1-9 cm, 9.1-12 cm, and > 12.1 cm. The resulting distribution curve was used as the basis for shrub selection for testing so that each treatment was applied to similarly sized shrubs in each of the 5 classes.

The 14 treatments tested in this study included an untreated stump control; diesel oil only; TORDON RTU undiluted; TORDON 22K undiluted and as 20% and 5% dilutions in water; ROUNDUP undiluted and as 20% and 5% dilutions in water; and GARLON 4 undiluted and as 20%, 10%, 5% and 2% concentrations in diesel oil. Each treatment was applied to 25 stumps.

Each shrub was cut with a chainsaw as close to the ground as possible (usually less than 15 cm). Treatments were immediately applied to all cut surfaces. Speed was essential in treatment application, as studies by Hay (1956) have shown that the negative pressure in the xylem which facilitates the deep penetration (to a maximum of 60 cm) of herbicides into the stump is lost in as little as 5 minutes. Herbicide application dates were May 21, 25, and 31, 1984. A brief, light rain fell on May 21st during application. All other applications were in dry weather conditions.

Stumps were monitored for resprouting, cambium death, and vigor of resprouts. Although herbicides were not directly applied to any native species, non-target vegetation within a 1-m radius was monitored for possible reactions to the treatments.

RESULTS AND DISCUSSION

TORDON RTU and undiluted GARLON 4 were the most effective cut-stump control treatments for Russian olive (Table 3). Of the 25 stumps treated with GARLON 4, one had resprouted by the fourth month. This stump produced 7 unhealthy shoots which grew to an average height of 10 cm. These shoots exhibited a gradual decline in vigor over the next 7 months, and by one year post treatment all had died. A cambium vigor check at one year confirmed no stumps were alive. Of the stumps treated with TORDON RTU, one produced a single, unhealthy shoot by the fifth month. This shoot was dead by the sixth month, however, and no additional resprouting was observed on this stump for the remainder of the study. A vigor check conducted at 6 months confirmed no viable cambium on any of the TORDON RTU-treated stumps. Control effectiveness did not vary among the 5 size classes of olive for these 2 treatments or for any of the following treatments.

The undiluted TORDON 22K, ROUNDUP, and the 20% GARLON 4 treatments showed good control effectiveness, with only 12%,

Table 3. Response of Russian olive (Linociera ligustrina) to cut stump control treatments (% plants resprouted) in Hawaii Volcanoes National Park, 1984-1985.

Treatment*	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
CONTROL	36	92	92	92	96	100	100	100	100	100	100	100
DIESEL	24	92	100	100	100	100	100	100	100	100	100	100
TORDON RTU	0	0	0	0	4	0	0	0	0	0	0	0
TORDON 22K												
100%	0	0	4	a	12	16	16	16	16	16	16	12
20%	4	a	28	40	40	44	44	48	52	52	64	52
5%	0	16	60	76	92	100	96	96	96	96	96	96
ROUNDUP												
100%	0	0	4	12	12	a	4	a	a	8	a	12
20%	0	12	16	28	28	32	32	32	36	36	36	48
5%	0	20	40	80	92	92	96	100	96	100	96	96
GARLON 4												
100%	0	0	0	4	4	4	4	4	4	4	4	0
20%	0	0	4	4	4	a	12	20	16	16	12	20
10%	a	a	12	12	24	14	28	28	28	28	36	36
5%	a	a	16	20	28	36	44	48	56	60	52	52
2%	8	16	24	32	40	48	56	56	60	64	60	60

* n = 25 plants in each treatment

12%, and 20% of the stumps resprouting after one year, respectively. In addition, there was an overall reduction in the number of new shoots which emerged from those stumps which did resprout, when compared to the stumps in the control group.

Twenty percent concentrations of TORDON 22K in water, ROUNDUP in water, and GARLON 4 at 2%, 5%, and 10% concentrations in diesel oil were only marginally successful, with resprouting rates ranging from 36% to 60% at one year. Four treatments, the untreated stump, diesel oil only, and 5% concentrations of both TORDON 22K and ROUNDUP in water were totally ineffective in controlling Russian olive, with resprouting between 96% and 100%.

The untreated control and diesel oil treatments showed the highest initial resprouting (36% and 24% of the stumps used for those treatments, respectively, after one month). Four other treatments which had resprouting after one month were: 20% TORDON 22K in water (4% resprouting); and 2%, 5%, and 10% GARLON 4 in diesel oil (8% resprouting each). Resprouting increased to 92% after 2 months for the untreated and diesel oil treatments, and by the sixth month this had increased to 100% for both treatments.

A rapid increase in the number of resprouting stumps during the third through sixth months was observed on the 5% and 20% concentrations of TORDON 22K and ROUNDUP; and on the 2%, 5%, and 10% GARLON 4 treatments. By the seventh month these treatments had resprouting rates of 96% and 44% (5% and 20% TORDON 22K, respectively); 96% and 32% (ROUNDUP at 5% and 20%, respectively); and 48%, 36% and 24% (GARLON at 2%, 5% and 10%, respectively). At this time there was a leveling off in the number of resprouting stumps in these treatments, with only slight increases for the duration of the study. A cambium vigor check conducted at one year revealed many stumps within these treatments which were still alive, although they had not yet resprouted.

During the course of this study, some characteristic deformities caused by the herbicides were observed on resprouting shoots. Stumps treated with TORDON 22K produced etiolated shoots, and leaves with abruptly acuminate tips as opposed to the normal narrowly acute tips. ROUNDUP resulted in swollen tissue masses covered with hundreds of tightly clustered buds. Although most of the bud masses had formed by the fourth month, the growth rate of these buds was very slow (less than 4 cm/month as compared to the control average of almost 12 cm/month).

<u>EFFECTS ON NON-TARGET NATIVE SPECIES</u>

Monthly observations of non-target native vegetation within 1 m of treated stumps showed no adverse effects on 'ohi'a, 'a'ali'i (<u>Dodonaea eriocarpa</u> Sm.), and mamane (<u>Sophora chrysophylla</u> (Salisb.) Seem.). This does not imply that the herbicides tested have no effect on these species; few mamane were exposed, for example. The herbicides applied on the Russian olive stumps apparently remained very localized on the target species and did not volatilize into the atmosphere or leach into the surrounding soil in sufficient concentrations to harm native species in the area. Tests were done in fairly dry areas, and little precipitation occurred during application.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

Based on the results of these tests, either TORDON RTU or undiluted GARLON 4 are effective treatments when applied to cut Russian olive stumps. TORDON RTU is less expensive on a per use basis and presents a lower hazard to the applicator. The oral LD_{50} (the dose which is lethal to 50% of rats tested) of triclopyr (the active ingredient in GARLON 4) is 630 mg of chemical/kg of body weight, and that of picloram is 8,200 mg/kg (the lower the number the higher the toxicity) (Berg 1985). Both herbicides are easy to apply, and residual activity and nsn-target hazards do not appear to be a problem. Therefore, TORDON RTU is the preferred treatment on cut stumps of Russian olive. No further research appears to be necessary to improve control techniques for mature olive shrubs, or to substantiate non-target hazards for this technique on this species.

FOLIAR APPLICATION OF HERBICIDES ON RUSSIAN OLIVE

MATERIALS AND METHODS

Sixty healthy Russian olive shrubs ranging in height from 85 cm to 165 cm were selected from the Ainahou Ranch area of HAVO. The foliar treatments tested were: 5% aqueous solutions of ROUNDUP, GARLON 4, and TORDON 22K. Each treatment was applied to 15 shrubs.

Height measurements of Russian olive shrubs were taken prior to treatment; however, no attempt was made to categorize shrubs into height classes. Plants were sprayed to wet, using hand pump pressurized sprayers with even flat-fan nozzles. Pressure was regulated at 20 psi. All treatments were applied on June 18, 1984 under sunny skies with winds estimated at 8 km/hr. No rain fell for at least 6 hours after treatment.

The numerical categories used to evaluate plant response to the herbicides included such characteristics as chlorosis, cambium vigor, leaf desiccation and abscission (leaf drop), as well as presence and vigor of resprouts, as follows:

1 = healthy, normal;
2 = < 50% leaves chlorotic;
3 = > 50% leaves chlorotic;
4 = < 50% leaves desiccated, cambium alive;
5 = > 50% leaves desiccated, cambium alive;
6 = 100% leaves desiccated and/or defoliated, cambium dead.

Individuals were monitored monthly for a period of one year, although plant responses had peaked by 8 months.

No native vegetation was directly sprayed except that growing among the test plants. Monitoring included observations of these native plants as well as natives within a 2-m radius which could have been exposed to incidental spraying or drift.

RESULTS AND DISCUSSION

The most effective herbicide tested as a foliar spray on Russian olive was the 5% concentration of GARLON 4 in water (Table 4). Results showed that one month after treatment 87% of the treated individuals exhibited severely desiccated foliage. Foliage remained attached to branches for several months following treatment. Cambium vigor evaluations at 8 months and one year indicated complete death of all shrubs. At one year, control was rated at 100%.

Russian olive shrubs treated with 5% ROUNDUP in water reacted with rapid and heavy defoliation of foliage, while cambium tissue remained healthy. Two months after treatment, 93% of the individuals were totally defoliated. At 3 months, resprouting of 2 individuals was noted; and at 12 months resprouting was observed on 47% of the treated individuals. Of the 8 individuals which had not resprouted at one year, 5 retained healthy cambium tissue and were considered to have potential for resprouting.

It is notable that resprouting buds on the individuals treated with ROUNDUP were characteristically abnormal. Swollen tissue masses formed at branch nodes from which large numbers of tightly clustered buds emerged. These buds remained less than 1 cm in length for 5 months before resuming a retarded growth rate. At one year, buds remained less than 5 cm in length; it is not known if this abnormal growth will subsequently normalize.

It is believed that the rapid and widespread defoliation which characteristically followed ROUNDUP treatments on Russian olive could only have reduced the effectiveness of this herbicide. If the leaves were aborted before sufficient amounts of the herbicide had entered the vascular systems of the plants, effectiveness would have been greatly diminished.

Rapid defoliation has been reported for other weed species treated with ROUNDUP and other herbicides, especially at high concentrations (Motooka et al. 1982). For example, 2,4,5-T, a phenoxy herbicide used extensively in the United States prior to 1980, was used in high concentrations as an ingredient in Agent Orange, an herbicide used as a defoliant in the Viet Nam War. In this study, it is not known whether the defoliation of Russian olive prevented translocation of ROUNDUP, or whether the concentration used was high enough to physically burn off the leaves. Olive shrubs treated with

Table 4. Plant response to foliar spray tests on Russian olive, Hawaii Volcanoes National Park, 1985. (Numbers in table represent response category means for each test.)

Month Monitored	Treatment*			
	CONTROL	ROUNDUP 5%	GARLON 4, 5%	TORDON 22K, 5%
JUL	1.0	4.3	4.7	2.1
AUG	1.0	4.9	5.0	2.5
SEP	1.0	4.4	5.1	1.5
OCT	1.0	4.4	5.7	1.7
NOV	1.0	4.4	5.6	2.0
DEC	1.0	4.3	5.5	2.0
JAN	1.0	4.3	5.5	1.9
FEB	1.0	4.9	6.0	1.7
MAR	1.2	4.5	6.0	1.9
APR	1.0	4.5	6.0	1.6
MAY	1.0	4.3	6.0	1.5
JUN	1.0	4.7	6.0	1.6

* n = 15 plants/treatment

Olive plant response categories:

1 = unaffected, healthy, normal
2 = < 50% leaves chlorotic
3 = > 50% leaves chlorotic
4 = < 50% leaves desiccated/defoliated, cambium viable
5 = > 50% leaves desiccated/defoliated, cambium viable
6 = 100% foliar desiccation, cambium dead

GARLON 4 did not become defoliated until approximately 6 months after treatment, allowing sufficient opportunity for complete translocation of this systemic herbicide. The ester formulation of GARLON 4 allows penetration through cell walls of both the leaves and the thin bark on olive, likely contributing to the success of this treatment.

Response of Russian olive shrubs to foliar treatments with 5% TORDON 22K in water was negligible. Two months following treatment, 40% of the individuals exhibited light chlorosis on fewer than 50% of the leaves. Twenty percent of the individuals seemed unaffected by the herbicide treatment. A few individuals exhibited some leaf desiccation and deformation of initial resprouting foliage. Subsequent resprouting, however, was normal. Ten months after treatment, 60% of the tested individuals showed a light chlorosis and vigorous resprouting, while the remaining 40% were normal and healthy.

EFFECTS ON NON-TARGET NATIVE SPECIES

Incidental herbicide drift affected some non-target plants growing within 1 m of target olive shrubs. Most 'a'ali'i which received herbicide drift of 5% GARLON 4 reacted with rapid leaf desiccation and, in some cases, total defoliation, but subsequently recovered. However, 2 severely affected 'a'ali'i, which received a spray dose equal to that for the target species, did die. Results for several non-target 'a'ali'i plants demonstrated that branches heavily hit with GARLON 4 defoliated and declined to apparent death, while untreated branches on the same shrub remained healthy. This suggests minimal translocation. Pukiawe (*Styphelia tameiaemeiae* (Cham.) F. Muell.) exhibited localized leaf desiccation with subsequent recovery when exposed to all herbicides tested. 'Ulei (*Osteomeles anthyllidifolia* (Sm.) Lindl.) received only very light incidental drift from all 3 herbicides and seemed unaffected.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

Although 5% GARLON 4 in water as a foliar spray was found to be an effective control for Russian olive, the potential hazards of this treatment may preclude its use for widescale control efforts. Spraying shrubs which are greater than 1 m in height presents a high probability of exposure by drift to non-target species as well as to the applicator. Therefore, this treatment is recommended only in situations where olive shrubs are less than 1 m in height and where native plants are not in close proximity. Further research is needed to find the lowest effective concentration of GARLON 4. A lower rate would reduce cost and possible hazards to the native vegetation and to the applicator. In the process of determining efficacy, more data on non-target responses of native species can be obtained.

HERBICIDE TESTS ON RUSSIAN OLIVE SEEDLINGS

MATERIALS AND METHODS

Fifty-four 0.25 m^2 plots were chosen under mature Russian olive trees in the Ainahou area of HAVO. Prior to treatment, olive seedlings within each plot were counted and height range was recorded for each plot. Seedling counts in the test ranged from 29-331 per plot, with heights ranging from 1-107 cm. Six plots were selected for each treatment; the mean seedling count for each treatment was within 5% of the grand mean for all the plots (each treatment was applied to approximately the same number of seedlings). A visual estimation of the percentage of seedlings taller than 15 cm within each plot was also made. Non-target native plant species growing within the plots were identified and monitored for possible reactions to the treatments. Pretreatment vigor was recorded for both target and non-target species.

Treatments tested included 1% and 5% concentrations of: ROUNDUP, TORDON 22K, GARLON 4, and AMITROL T.

Herbicides were applied with 500-ml trigger spray bottles set for a coarse spray. Treatments were applied at a rate of 600 1 of spray solution/ha on July 20, 1984 under partially cloudy skies with a 8 km/hr breeze. No rain fell for at least 6 hours after spraying.

Seedling response to treatments was evaluated through use of categories as follows:

0 = normal, healthy;
1 = chlorosis, < 25% death;
2 = foliar desiccation, 25-50% death;
3 = defoliation, 50-75% death;
4 = 100% cambium death.

Observations of all vegetation for changes in vigor and any other reactions were conducted at monthly intervals for 6 months.

RESULTS AND DISCUSSION

Russian olive seedling response to the treatments had peaked by the fourth month and remained unchanged through the sixth month when the test was terminated (Table 5). Resprouting had occurred by this time.

Five percent GARLON 4 produced 100% control of Russian olive seedlings by the fourth month. Treated seedlings were defoliated and desiccated, with no viable tissue. No resprouting was observed during the test.

A range of 50 to 90% seedling mortality was achieved with the 5% ROUNDUP, 5% AMITROL T, and 1% GARLON 4 treatments. Within this group, the 1% GARLON 4 treatment produced the most consistent results, with 75-90% control in all 6 plots by the fourth month.

Table 5. Results of herbicide spray trials on Russian olive seedlings, Hawaii Volcanoes National Park, 1984-85. (Numbers in table represent response category means for each test.)

Month Monitored	GARLON 4 5%	GARLON 4 1%	TORDON 22K 5%	TORDON 22K 1%	ROUNDUP 5%	ROUNDUP 1%	AMITROL T 5%	AMITROL T 1%	Untreated Control
AUGUST	2.2	1.7	1.2	0.7	1.3	0.7	1.0	0.8	0.5
SEPTEMBER	3.5	2.3	1.2	0.2	1.5	0.7	1.2	0.8	0.0
OCTOBER	3.8	2.7	1.0	0.3	1.8	1.0	1.7	0.7	0.5
NOVEMBER	4.0	2.5	1.3	0	1.2	0.8	1.8	0.8	0
DECEMBER	4.0	3.0	0.8	0.7	1.8	0.7	2.5	0.8	0.2
JANUARY	4.0	3.0	1.0	0.3	2.0	0.8	2.3	1.0	0.2
Sample Size	671	671	691	685	683	691	671	668	689

Olive seedling response categories:

0 = normal, healthy
1 = chlorosis, < 25% death
2 = foliar desiccation, 25-50% death
3 = 50-75% death, defoliation
4 = 100% cambium death.

Five percent TORDON 22K resulted in 75% control of all the treated seedlings in one plot, but only 25% control in the remaining 5 plots. One percent concentrations of TORDON 22K, ROUNDUP, and AMITROL T caused between 0 and 50% mortality of Russian olive seedlings. The predominant symptom produced by these treatments was foliar chlorosis, which appeared by the first month. By the fourth month, however, the seedlings had recovered and appeared healthy, with no sign of chlorosis in any of the plots for the 1% treatments. Seedling size did not appear to be a factor in treatment effectiveness. Both large (height > 15 cm) and small seedlings were similarly affected within each of the herbicide treatments.

Heavy rains which fell in November 1984 apparently initiated the germination of Russian olive seeds in the test area and allowed detection of differences in the frequency of seed germination inside and immediately outside the test plots 4 months after treatment. Concentration of seeds in the soil was assumed to be the same in both locations. General observations indicated no residual activity with any of the treatments by this time, as seedlings appeared within all plots with the same apparent frequency as outside.

Differences in seedling responses to the various treatments were observed which could be important in determining effectiveness of treatments. AMITROL T produced creamy-white chlorotic spots on the leaf surface, with light (< 25%) leaf drop on those seedlings whish were not quickly killed. The seedlings responded to ROUNDUP by defoliating in moderate (25-75%) to heavy (> 75%) amounts very shortly after treatment. Again, this reaction could have limited the amount of herbicide that entered the vascular system of the seedling. None of the plants treated with either concentration of GARLON 4 shed their leaves. The leaves remained attached to seedlings long after desiccation and death had occurred. This would allow full uptake of GARLON 4 into the seedling, and therefore maximize effectiveness of the herbicide. Similarly, leaf drop was not observed on TORDON-treated seedlings. This did not enhance the effectiveness of the herbicide results since, except for one plot, the only symptoms observed were minor chlorosis and some leaf curling, from which most plants recovered by the fourth month.

EFFECTS ON NON-TARGET NATIVE SPECIES

All results are based on chance occurrences of native species within plots and do not represent a designed test for effects on natives (Table 6). Species evaluated were directly sprayed during treatments, as they were growing within test plots. The only native plants treated with 5% GARLON 4, one 'ulei and one 'a'ali'i seedling, died. Another 'a'ali'i seedling treated with 5% TORDON 22K also died. No other adverse effects were observed in this test, although very low numbers of these plants were exposed to treatments.

Table 6. Effects of herbicide treatments for control of Russian olive seedlings on non-target native species within 0.25 m^2 treated plots.

Species	Life Stage**	Treatment: ROUNDUP 5%	ROUNDUP 1%	TORDON 22K 5%	TORDON 22K 1%	GARLON 4 5%	GARLON 4 1%	AMITROL T 5%	AMITROL T 1%	Total No. Plants Treated
Carex wahuensis	M		N/1***	N/1					N/2	4
Coprosma sp. (pilo)	S								N/1	1
Dodonaea eriocarpa ('a'ali'i)	S		N/1	H/1		H/1		N/1		4
Osteomeles anthyllidifolia ('ulei)	S					H/1		N/1)		2
Sophora chrysophylla (mamane)	S									1
Styphelia tameiameiae (pukiawe)	S			N/1	N/I					2

* Plant response categories:

- H = Heavy
- M = Moderate
- L = Light
- N = No effect
- Blank = Not exposed to treatment.

** Life stage: S = Seedling; M = Mature, capable of sexual reproduction.

*** Number of plants exposed in each test.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

Based on this test, GARLON 4 is the most effective herbicide for Russian olive seedlings. However, the lowest effective rate appears to be somewhere between the 2 tested rates (1% and 5%). It is recommended that further testing be conducted to find the lowest effective rate. More information on hazards to non-target native plants could be obtained in the process.

The 3 control methods developed for Russian olive could be combined as part of an overall Russian olive removal strategy. One suggestion would involve a crew of 3 people using the cut-stump method to eliminate all olive plants taller than 1 m, followed by a crew of 2 Concentrating on seedlings and saplings, with either the foliar treatments or mechanical removal, depending on the proximity of native species. Follow-up treatments on seedlings could be scheduled 1 to 2 months after a rainy period, to allow time for seed germination. Follow-up treatments on seedlings would continue until the soil seed bank is exhausted. Studies on seed viability in the soil would be needed to determine the length of time necessary to exhaust the seed bank.

HERBICIDE TREATMENTS FOR TWO SPECIES OF SILKY OAK

The purpose of this test was to determine the sensitivity of 2 species of silky oak (*Grevillea robusta* and *G. banksii*) to a variety of herbicides when applied via basal bark, continuous frill cuts.

MATERIALS AND METHODS

One hundred twenty trees of each species were chosen from healthy populations just outside the Ka'u boundary of HAVO. The area, a dry, scattered *Metrosideros* community with native shrubs and alien grasses, had been partially converted to pasture. Prior to tree selection, a 10-m wide belt transect was established through populations of both *G. robusta* and *G. banksii* to determine the tree size distribution (based on basal trunk diameter) of the silky oak population. Four size classes were established: 3-8 cm, 8.1-13cm, 13.1-18 cm, and 18.1-23 cm. Fifteen trees of each species were selected for each treatment to parallel the size distribution determined by the belt transect.

Identical treatments were used on both species: GARLON 4 diluted in diesel oil at 2.5%, 5%, and 10% concentrations; TORDON 22K diluted in water at 5%, 10%, and 20% concentrations; and control treatments of diesel oil only and water only. Each of the 8 treatments was applied to 15 trees. Overlapping rather than spaced frill cuts were used because tests by Leonard (1957) showed them to be more effective. The frill cuts were made with a hatchet around the entire circumference of each trunk less than 15 cm from the ground and deep enough to sever the cambium. A single, solid stream of the appropriate herbicide was squirted from a plastic squeeze bottle into the trough created by the frill cuts. The technique used for frill cut treatment is shown in Appendix B.

The application dates were August 20, 1984 for G. banksii and August 29, 1984 for G. robusta. Weather on both days was overcast but dry. Treatments were monitored at monthly intervals for a period of one year. Tree responses to treatments were evaluated with response categories similar to those described for other species:

0 = no effect, normal healthy growth;
1 = less than 25% defoliation, cambium alive;
2 = 50% defoliation, cambium alive;
3 = 75% defoliation, cambium alive;
4 = 100% defoliation, cambium alive;
5 = 100% defoliation, cambium dead.

RESULTS AND DISCUSSION

G. banksii. All of the GARLON 4 treatments (2.5%, 5%, and 10% in diesel oil) and 2 of the TORDON 22K treatments (5% and 20% in water) resulted in 100% mortality of treated individuals within 11 months (Table 7). Slightly less effective was 10% TORDON 22K in water, which killed 87% (13) of the treated trees by the seventh month, with the remaining 2 trees exhibiting 50-75% initial leaf desiccation, moderate cambium vigor, and basal resprouting by the ninth month. A characteristic progression of symptoms was apparent in all TORDON 22K and GARLON 4 treatments. Trees demonstrated leaf chlorosis over 50-75% of the tree within one month, followed by increased leaf desiccation and simultaneous decline of cambium vigor both above and below the frill cut. The highest concentration of both GARLON 4 and TORDON 22K resulted in an accelerated plant reaction and more rapid death of treated individuals. The interval between treatment and death was 5-6 months for the highest concentrations, compared to 11 months for the lower concentrations. It is notable that lower concentrations of GARLON 4 were sufficient to eventually achieve a success rate comparable to higher concentrations of TORDON 22K (e.g. GARLON 4 at 2.5% was as effective as TORDON 22K at 5%). Younger trees (3-8 cm basal diameters) were generally more susceptible to all of the herbicides and declined more rapidly than the larger trees.

The diesel oil-only treatment produced greater than 75% leaf desiccation without cambium decline on 2 of 15 individuals. The remaining 13 trees demonstrated a temporary mild to moderate leaf chlorosis, followed by heavy resprouting below the frill cut. The water-only treatment did not cause any discernible decrease in leaf or cambium vigor. In addition, basal resprouts occurred on 3 water-only treated trees. The frill cuts were healed by the tenth month on all individuals in both the diesel oil-only and water-only tests.

G. robusta. The 3 concentrations of GARLON 4 (2.5%, 5% and 10% in diesel oil) produced 100% control of G. robusta

Table 7. Mean response ratings for Grevillea banksii and G. robusta subjected to herbicide treatments. (Numbers in table represent response category means for each test.)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Grevillea banksii												
DIESEL OIL ONLY	1.0	0.6	0.5	0.7	0.9	1.0	1.1	1.9	1.6	1.7	1.3	1.6
GARLON 4												
10%	3.3	3.8	3.9	4.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
5%	2.5	3.3	3.7	4.5	4.7	4.8	5.0	5.0	5.0	5.0	5.0	5.0
2.5%	2.5	3.1	3.3	4.2	4.4	4.6	4.7	4.7	4.7	4.9	5.0	5.0
TORDON 22K												
20%	3.8	3.9	3.6	4.7	4.6	4.9	4.9	5.0	5.0	5.0	5.0	5.0
10%	3.4	3.6	3.7	4.3	4.4	4.6	4.8	4.7	4.7	4.7	4.7	4.7
5%	3.5	3.5	3.5	4.3	4.3	4.5	4.7	4.8	4.7	4.9	5.0	5.0
WATER	0.6	0.2	0.1	0.3	0	0.1	0	0.1	0	0.1	0.2	0.2
Grevillea robusta												
DIESEL OIL ONLY	0	0	0	0	0.1	0	0	0.3	0.2	0.8	0.8	0.5
GARLON 4												
10%	2.9	4.0	4.0	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
5%	2.4	4.0	3.9	4.9	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2.5%	2.4	3.8	4.0	4.0	4.8	4.9	4.9	5.0	5.0	5.0	5.0	5.0
TORDON 22K												
20%	2.9	3.6	3.8	4.5	4.6	4.8	4.9	4.9	4.8	4.8	4.8	4.9
10%	2.5	3.3	3.5	4.1	4.1	4.3	4.3	4.4	4.2	4.6	4.7	4.4
5%	2.0	2.3	2.3	2.9	3.0	3.1	3.2	3.5	3.1	3.5	3.6	3.6
WATER	0.5	0	0	0	0	0	0	0.1	0	0	0	0

*
(n = 15 trees/test)

Plant response categories:
- 0 = no effect, normal healthy growth
- 1 = < 25% defoliation, cambiun alive
- 2 = 50% defoliation, cambium alive
- 3 = 75% defoliation, cambium alive
- 4 = 100% defoliation, cambium alive
- 5 = 100% defoliation, cambium dead

within 8 months, In all 3 treatments, foliage rapidly desiccated but did not abscise for several months. Cambium vigor decline both above and below the frill cut was gradual. TORDON 22K, at 20% in water, was slightly less effective, with 93% control of treated individuals at one year.

Sixty-seven percent of the trees treated with 10% TORDON 22K were killed, with the remaining trees showing 50% leaf desiccation and defoliation. Spindly and severely deformed resprouts appeared on these surviving trees. Subsequent resprouts were less severely deformed, indicating possible recovery of the tree. The 5% TORDON 22M treatments killed only 13% of the silky oak trees, with the remaining trees exhibiting a similar pattern of progressively diminishing resprout deformities.

In diesel oil-only treatments, the vegetative portion above the frill cut died on 2 trees. However, the cambium remained in good vigor below the frill cut, and by the tenth month healthy resprouts were appearing, The remaining trees in both the diesel oil-only and water-only treatments were apparently unaffected, with the diesel oil-treated trees exhibiting numerous healthy basal sprouts below the frill cut by the sixth month.

EFFECTS ON NON-TARGET NATIVE SPECIES

Native species within a 1-m radius of treated trees included 'ohi'a, 'akia (Wikstroemia sp.), and 'a'ali'i. No adverse effects were noted on any of these species.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

Results indicated that 2.5% GARLON 4 in diesel oil was the lowest concentration of herbicide effective in controlling both species of Grevillea. This low herbicide concentration has the advantage of reducing the hazard to the applicator and minimizing quantity and therefore cost of herbicides used. The basal frill application of 2.5% GARLON 4 in diesel oil is therefore recommended. No future research on the control of silky oak is anticipated, and it is recommended that implementation of silky oak control begin as soon as possible.

FOLIAR HERBICIDE APPLICATIONS FOR FLORIDA BLACKBERRY

MATERIALS AND METHODS

Seventy 3-m^2 plots were selected for treatment from a Rubus arsutus population in the Kipuka Ki section of HAVO. This area is a closed canopy, mesic Metrosideros/Acacia/Sapindus forest, with mixed native shrubs and alien grasses in the understory. Elevation is 1,280 m, and mean annual rainfall and temperature are 1,890 mm and 15° C. Untreated buffer zones at least 3 m wide were included around all plots to prevent any overlap of treatments.

Prior to herbicide treatment, a vegetation survey was conducted to establish presence or absence of native and alien plants growing within each plot. Percent cover and vigor (0-5 scale) of R. arautus were recorded. Vigor of all non-target vegetation was also noted prior to treatment and at one year post treatment. The vigor scale used to evaluate the test plots on a month to month basis was:

0 = > 90% stems and foliage alive, excellent vigor;
1 = 75-90% stems and foliage alive;
2 = 50-75% stems and foliage alive, moderate vigor;
3 = 10-50% stems and foliage alive;
4 = < 10% stems and foliage alive, poor vigor;
5 = death.

Two foliar spray techniques were tested: conventional sprays, and drizzle sprays. (The drizzle or "magic wand" method developed by Uyeda and described by Motooka et al. (1983) is a high-concentration, low-volume, non-atomizing technique using pressure-regulated sprayers fitted with an orifice disk instead of a conventional nozzle tip. The orifice disk produces a single, thin stream of liquid rather than a spray.) The conventional sprays included 0.5% and 2% concentrations v/v of GARLON 4, TORDON 22K, ROUNDUP, and AMITROL T. These were applied with water as the carrier at a volume of 190 l/ha. Pressure was regulated at 30 psi with a spray volume of 9.5 l/ha for the drizzle sprays. A #20 orifice disk was used, with water as the carrier. A spreader-sticker, TRITON 1956B (Ortho), was added to the conventional sprays at 0.5% v/v and to the drizzle sprays at 1% v/v.

All herbicide treatments were applied sequentially as suitable plots were encountered in the field on October 29, 1984 under partially cloudy skies. A very light rain fell briefly during application, but no rain fell for at least 4 hours after application. Winds were estimated at 8 km/hr.

RESULTS AND DISCUSSION

Although no treatment was shown to be totally effective in the control of Rubus arautus, the most successful was a conventional spray of 2% ROUNDUP in water (Tables 8 and 9). All 5 of the blackberry plots subjected to this treatment reacted with a gradual decline in vigor. Symptoms included foliar chlorosis and desiccation, followed by stem desiccation and subsequent defoliation. Vigor progressively declined until the sixth month, when plant response stabilized. Two of the 5 plots exibited 100% mortality with no resprouting after one year. A third plot was similarly affected; however, at one year, healthy root sprouts were observed in this plot. The remaining 2 plots exhibited greater than 90% foliar and stem mortality and a reduction in blackberry cover of 86% and 60% at one year. Several stems which survived the herbicide treatment remained dormant for up to 10 months before producing stunted and severely deformed resprouts in tight clusters at the nodes. While these initial resprouts remained stunted, resprouts which appeared during the eleventh month appeared healthy.

Table 8. Response of Rubus argutus to foliar herbicide treatments, Hawaii Volcanoes National Park, 1984-85. (Numbers in table represent response category means of individuals treated in each test.)

Treatment*	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	PRETREATMENT
UNTREATED CONTROL	0.7	0.8	0.8	0.3	0.8	0.8	0.5	0.7	0.5	1.0	0.5	1.0	1.4
GARLON 4													
40% drizzle	4.0	4.0	4.0	5.0	4.8	4.4	4.0	2.4	0.8	1.6	1.0	1.2	1.8
2% conventional	4.0	4.0	4.0	5.0	4.2	3.8	3.8	3.0	2.2	2.4	1.8	1.0	1.4
0.5% conventional	4.0	4.0	4.0	3.6	3.4	3.2	3.2	3.2	1.4	1.8	1.6	1.0	1.2
TORDON 22K													
20% drizzle	3.2	4.0	3.8	4.4	3.0	2.6	2.2	1.2	0.8	1.0	0.6	1.0	1.2
2% conventional	4.0	3.8	3.6	4.2	3.6	3.2	2.4	1.8	1.6	2.0	1.4	1.0	1.0
0.5% conventional	3.4	3.4	3.2	3.4	2.4	2.0	1.8	1.2	1.2	1.0	0.4	1.0	1.2
ROUNDUP													
20% drizzle	2.6	2.8	3.2	3.6	3.0	3.8	4.0	3.6	2.6	2.6	3.0	2.2	1.4
2% conventional	2.4	3.0	3.0	4.2	3.6	4.6	4.6	4.6	4.4	4.8	4.2	2.6	1.6
0.5% conventional	2.6	3.0	3.0	3.6	3.2	3.4	3.6	3.6	3.0	2.6	2.4	1.4	1.6
AHITROL T													
40% drizzle	2.4	2.0	2.2	1.2	1.4	1.2	1.4	1.2	0.8	1.4	1.0	1.0	1.4
2% conventional	2.0	3.2	2.0	1.2	1.2	0.8	1.0	0.8	1.0	1.0	0.4	1.0	1.2
0.5% conventional	2.4	1.2	1.0	0.6	1.0	1.2	1.2	1.2	1.0	1.2	0.8	1.2	1.4

* n = 5 plants/treatment

Plant response categories:

0 = > 90% stems and foliage alive, excellent vigor
1 = 75-90% stems and foliage alive, excellent vigor
2 = 50-75% stems and foliage alive, moderate vigor
3 = 10-50X stems and foliage alive, moderate vigor
4 = < 10% stems and foliage alive, poor vigor
5 = 100% death, no resprouts

Table 9. Cover change of Rubus argutus within 3 m^2 plots one year after treatment.*

Plot	AMITROL T 40%	AMITROL T 2.0%	AMITROL T 0.5%	GARLON 4 40%	GARLON 4 2.0%	GARLON 4 0.5%	ROUNDUP 20%	ROUNDUP 2.0%	ROUNDUP 0.5%	TORDON 22K 20%	TORDON 22K 2.0%	TORDON 22K 0.5%	UNTREATED CONTROL	
I														
Pretreatment	80	90	80	100	80	90	80	70	80	90	90	90	70	80
Post treatment*	30	70	20	90	30	90	5	10	5	90	50	90	90	90
2														
Pretreatment	90	90	60	90	100	60	90	90	90	100	100	70	80	80
Post treatment	90	90	90	25	70	100	80	0	90	80	80	90	80	80
3														
Pretreatment	80	90	70	80	50	80	90	50	80	90	80	90	80	100
Post treatment	75	80	90	90	10	70	10	0	20	90	70	100	80	100
4														
Pretreatment	90	70	80	80	80	80	100	70	80	80	90	95	90	80
Post treatment	100	70	80	10	80	90	60	< 1	80	50	80	100	80	60
5														
Pretreatment	90	100	60	90	90	70	80	100	60	80	60	90	100	80
Post treatment	90	100	30	75	70	50	75	40	5	50	10	90	100	100

* Visual estimates one year post treatment. n = 5 plots/treatment, except 10 plots for control.

The remaining 2 ROUNDUP treatments, 0.5% conventional spray and 20% drizzle, resulted in less consistent control at one year. Of the 5 plots treated with the 0.5% spray, 3 had Rubus cover reductions of 75%, 92%, and 94%, while cover in the remaining 2 plots showed no decrease. In the 5 plots treated with the 20% drizzle application, 2 plots showed cover reductions of 89% and 94%, while plants in the remaining 3 plots were less affected, with 6%, 11%, and 40% blackberry cover reductions. Although there was a high mortality of treated stems and foliage (> 90%) in 3 of the 0.5% ROUNDUP and 4 of the 20% ROUNDUP treatments, healthy and vigorous root and stem resprouts occurred in all plots of these 2 treatments at one year.

Results were highly variable for all 3 GARLON 4 treatments (0.5 and 2% conventional and 40% drizzle sprays). Blackberry cover reduction ranged from 0 to 80% with the 2% spray. For the 0.5% spray, response varied from an increase of 13% to a decrease of 88%; and for the 40% drizzle application, response varied from an increase of 67% to a decrease of 29%.

Typically, blackberry reacted quickly to the GARLON 4 treatments, with heavy leaf and stem desiccation by the first month. By the fourth month 100% mortality of treated vegetation was observed in all 5 plots for both the 2% and 40% treatments. Sixty to 90% mortality was recorded for the 0.5% treatment plots. However, GARLON 4 was apparently unsuccessful in killing the root systems, as healthy root resprouts occurred in all of the GARLON 4 plots by the eighth month.

The 3 TORDON 22K treatments (0.5% and 2% conventional and 20% drizzle sprays) produced similar results on blackberry. The typical reaction sequence included foliar chlorosis and desiccation, followed by desiccation of stem terminals. The basal portions of the stems generally remained succulent, particularly on the larger stems. Stem mortality for the 0.5% spray was generally less than 40%. Two plots in each of the 2% and 20% treatments registered 100% mortality, with the remaining 3 plots in each of the 2 treatments ranging between 40% and 90%. Resprouts originating from the roots were first observed by the second month in a 0.5% treatment plot and occurred in all TORDON 22K-treated plots by the sixth month. The initial resprouts were deformed, with the leaf margins curling upward towards the midrib. Subsequent resprouts were less affected, and by one year, resprouts in all of the TORDON 22K plots were normal and healthy. Reduction in vegetation cover at one year varied widely in TORDON 22K-treated plots. Cover reduction was less than 45% for plants in the 5 plots in the 2% treatment. Rubus cover was reduceed by 38%, 38%, and 20% in 3 plots, with no reduction in the remaining 2 plots. Increases were recorded in 3 of the 5 plots treated with the 20% drizzle spray, while cover in the remaining 2 plots was unchanged.

The 3 AMITROL T treatments (0.5% and 2% conventional and 40% drizzle sprays) were ineffective in controlling blackberry. Only a temporary foliar chlorosis occurred on a few leaves. Treated plants quickly recovered, producing healthy sprouts by the third month.

Two control (untreated) plots showed no change in Rubus cover; 2 others showed increases of 10% and 20%; and one exhibited a 20% decrease at one year.

EFFECTS ON NON-TARGET NATIVE SPECIES

Plant species (endemic, indigenous and introduced) which were monitored for possible reactions to the herbicide treatments included the species listed in Table 10. Frequency of occurrence of these species in treatment plots is listed. Each non-target species may not have occurred within each herbicide treatment plot. Therefore, the information below reflects plant responses to specific herbicides in incidental spray situations. Data are presented to assist in gauging incidental impacts and do not reflect broad-scale, systematic testing of non-target species. Evaluations were made one year after treatment.

The results in Table 10 indicate that ROUNDUP is more detrimental to native species when applied as low-concentration, high-volume sprays, than with high-concentration drizzle spray application. One possible explanation is that high-concentration ROUNDUP physically burns plant tissue to the extent that systemic translocation is not possible. Another explanation involves poor coverage, a drawback to low-volume spray applications in general. It is possible that the poor coverage inherent in drizzle sprays resulted in untreated areas within treated plots. High-volume sprays resulted in uniform coverage, increasing the probability that all vegetation within a plot was treated.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

Although no treatment was found which provided total control of blackberry, the conventional foliar spray of 2% ROUNDUP in water would be useful in certain applications. This treatment, because of its effectiveness in greatly reducing the shade cover of blackberry for an extended period of time, could be used to assist in the regeneration of native tree species in areas where blackberry may be preventing this. ROUNDUP should not deter the germination of native species, as it is rapidly inactivated in soils with high organic matter and low pH (Sprankel et al. 1975). The treatment is within labeled application rates when used as prescribed. Post-treatment monitoring would be necessary, as resprouting of blackberry is likely. Treating large stands may need to be done in stages, as it may not be possible to reach the central portions of some thickets with the spray. Applicators must be aware of changing wind patterns when spraying blackberry stands taller than 1 m, to avoid spray drift which can be hazardous to both the applicator and to

Table 10. Responses of non-target native and introduced plants to herbicide treatments to control Rubus argutus.

Species	Treatment*											
	GARLON 4			ROUNDUP			AMITROL T			TORDON 22K		
	40%	2%	0.5%	20%	2%	0.5%	40%	2%	0.5%	20%	2%	0.5%
Endemic and Indigenous Species												
Acacia koa (Koa)		+	+	+	+		+	+		+	+	+
Asplenium sp.					+							
Coprosma sp. (Pilo)					+		+			+		+
Ipomoea congesta (Morning glory)	L-H**	+	+	L**	L-H**	L-H**	H**	+	+	+	+	+
Microlepia strigosa (Palapalai)					H							
Myoporum sandwicense (Naio)											+	
Pipterus albidus (Mamake)	+			+								+
Pteridium aquilinum var. decompositum (Kilau)	+	+	+	+	+	+	+	+	+	+	+	+
Sadleria cyatheoides (A'ma'u'ma'u)				+								
Sapindus saponaria f. inaequalis (Manele)				H			H**			H		
Sophora chrysophylla (Mamane)								M				
Introduced Species												
Commelina diffusa (Honohono)					+			+			H	
Cynodon dactylon (Bermuda grass)		+			H		+	+	+		+	+
Fragaria vesca (Wild strawberry)	+			+	+		+			+		
~~Holcus lanatus~~ (Velvet grass)		+		+	H	H		+				
Lythrum maritimum (Puka male)	+	+	+	+	+	H	+	+	+	+	+	+
Microlaena stipoides (Meadow ricegrass)		+	+	+		H					+	+
Paspalum dilatatun (Dallis grass)	+	+	+	*	H	+	+	+	+	+	+	H**
Pennisetum clandestinum (Kikuyu grass)	+		+			+	+		+	+		+
Setaria geniculata (Foxtail grass)			+						+			
Solanum pseudocapsicum (Jerusalem cherry)	L-H		L-H	+	+	L-H	+			+		L-H
Stenotaphrum secundatum (St. Augustine grass)								L				
Tritonia crocosmiflora (Montbretia)	+											
Verbena litoralis (Weed verbena)		H										
Veronica plebeia (Common speedwell)		+			+			+	+		+	

?

Table 10, continued.

Key:
+ = exposed to treatment, no adverse effects
blank = not present in plot, therefore not exposed to treatment
H = heavily impacted (death)
M = moderately impacted (defoliation/desiccation, severely chlorotic plants partially recovered)
L = light effects (light chlorosis, some defoliation, some plants unaffected, full recovery)

* Drizzle for highest concentrations, spray for middle and lowest concentrations

** Comments:

Treatment	
40% Garlon 4	four Ipomoea vines were treated: 2 of these of moderate to poor pretreatment vigor died, while the remaining 2, in excellent pretreatment vigor, were Unaffected.
20% Roundup	Three Ipomoea vines were treated. One declined from good to very poor vigor, while the remaining 2, in excellent vigor, were unaffected.
2% Roundup	Three Ipomoea vines were exposed. One in good vigor died, one declined from excellent to moderate vigor, and one increased from good to exceltent vigor.
0.5% Roundup	Three Ipomoea vines in good vigor were treated. One died, one declined to poor vigor, and one increased to excellent vigor.
40% Amitrol T	Three Ipomoea vines were treated. One, in poor vigor, died; one, in good vigor died, while the last vine, in excellent vigor, was unaffected. Sapindus seedlings in one plot were not found after treatment and are presumed to have died.
2% Amitrol T	One Sophora chrysophylla individual reacted to treatment with partial defoliation; however, subsequent resprouts were healthy and vigorous.
20% Tordon 22K	A cluster of Sapindus seedlings was not found and is presumed to have died.
0.5% Tordon 22K	One Paspalum clump in excellent vigor died, while the others were unaffected.

surrounding non-target species. Another critical factor involved in the treatment of blackberry deals with informing the general public where and when this activity is being conducted, to protect berry pickers from any contamination. The berries are commonly used as food in Hawai'i.

Further research is definitely needed to improve the methods already tested and to explore new treatments (perhaps combinations of herbicides and/or repeated treatment annually). Larger plot and sample sizes (including treating entire stands) would yield more accurate information on treatment effectiveness. Repeat treatment testing is necessary to ascertain if this would lead to complete control and the number of treatments necessary. Monitoring of areas where blackberry has been eliminated could yield valuable information on what is likely to colonize these areas. More information is needed on the effects of 2% ROUNDUP on native species, as this treatment is not target specific.

HERBICIDE TREATMENTS FOR YELLOW HIMALAYAN RASPBERRY

MA AIS AND)I

Three foliar sprays, 4 soil, and 10 cut-stump treatments were tested on yellow raspberry. Each treatment was applied to 5 plots. For the 3 foliar and 4 soil treatments, 35 3-m^2 plots were selected from a *Rubus ellipticus* population along the southern boundary of the small section of Ola'a Tract of HAVO. For the cut-stump tests, 50 individual plants located in the southwestern section of the large section of Ola'a Tract in HAVO were selected. Both areas are classified as open canopy tall 'ohi'a rain forest with predominantly hapu'u (*Cibotium* spp.) and native shrubs in the understory (Jacobi 1983). Elevation is 1,190 m, with mean annual rainfall of 2,494 mm. Mean monthly maximum temperatures ranged between 19° and 22°C.

Foliar sprays were applied via the drizzle or "magic wand" method in a water carrier at a spray volume of 21 l/ha. The 3 treatments tested were: 50% concentrations of GARLON 4 and of ROUNDUP, and a 25% concentration of TORDON 22K. Hand-pressurized sprayers fitted with #20 orifice disks were used. Pressure was regulated at 30 psi. Triton 1956B (Ortho) was added as a spreader-sticker at 1% v/v.

Four soil applications of TORDON 10K pellets were tested: topical broadcast treatments at 0.2 and 0.4 gm ae/m^2; and spot treatments at 0.2 and 0.4 gm ae/m^2. The spot treatments involved depositing all pellets in one spot in the center of the 3-m^2 plot.

The 9 treatments tested on cut stumps included: TORDON RTU; undiluted ROUNDUP, GARLON 4, and TORDON 22K; 5% and 20% dilutions of GARLON 4 in diesel oil; TORDON 22K in water; diesel oil only; and an untreated control. Trunks were severed at a height of < 10cm either with a hand pruning saw or with pruning shears, depending upon stem size. Treatments were applied immediately to the freshly cut surface with 500-ml plastic squeeze bottles.

All treatments were applied under partially cloudy skies but dry weather with winds estimated at 3 km/hr. Treatment application dates were May 5, 1985 for the foliar and soil treatments and July 22, 1985 for the cut-stump tests. No rain fell for at least 4 hours after treatment. Monitoring was conducted at monthly intervals for one year.

_R_. _ellipticus_ responses to foliar and soil treatments were determined by assigning plants to one of 6 vigor categories, as follows:

0 = healthy, no apparent effect;
1 = light effects, chlorosis < 50% of plant;
2 = chlorosis > 50% of plant;
3 = moderate effects, > 50% leaf desiccation/defoliation;
4 = 50-75% leaf desiccation/defoliation;
5 = 75%-90% plant death (cambium, stem desiccation);
6 = 90-100% plant death.

_R_. _ellipticus_ responses to cut-stump treatment were determined by assigning plants to one of 5 categories, as follows:

0 = apparently healthy, normal, resprouts;
1 = heavy resprouts with light abnormalities (chlorosis);
2 = moderate resprouts with abnormalities;
3 = light resprouts, with abnormalities;
4 = no resprouts, cambium alive;
5 = no resprouts, cambium dead.

RESULTS AND DISCUSSION

Foliar and Soil Treatments. Of the 3 foliar and 4 soil treatments tested, only the 50% GARLON 4 drizzle application proved to be effective in controlling yellow raspberry (Table 11). After one month, 4 of the 5 plots exhibited leaf and stem desiccation on greater than 50% of the treated plants. The remaining plot showed only light chlorosis on a few scattered leaves. Chlorosis remained until the fifth month, when all foliage appeared healthy. It is believed that this plot, through an error in application technique, received less than the prescribed dose of GARLON 4. For plants in the 4 plots which reacted to the GARLON 4 treatment, leaf and stem desiccation increased to 75-90%, with some defoliation by the second month. Reactions to the GARLON 4 treatment peaked by the fourth month after treatment, with greater than 90% defoliation and stem desiccation and no resprouting observed in 3 of 4 plots. Plant death in the fourth plot was 75-90%, with one healthy root resprout. No additional resprouting was observed in any of the GARLON 4-treated plots at one year.

ROUNDUP produced mild to moderate chlorosis with some stem desiccation in 3 of 5 plots. Subsequent resprouts on the more severely affected branches were deformed, with buds

Table 11. Response of Rubus ellipticus to foliar and soil herbicide treatments, Hawaii Volcanoes National Park, 1985-86. (Numbers in table represent mean values for response categories.)

Treatment*	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
ROUNDUP 50%	1.2	1.2	1.8	1.6	1.6	0.8	0.8	0.6	0	0.6	1.0	1.8
GARLON 4, 50%	3.4	4.0	4.2	4.8	4.4	4.0	4.0	4.4	4.2	4.6	4.8	5.2
TORDON 22K, 25%	1.8	2.0	2.0	1.4	1.6	0.8	0.8	0.6	0.4	0.2	0.2	0
TORDON 10K PELLETS BROADCAST												
0.4 gm	1.0	1.4	2.0	1.4	1.4	0.8	1.4	1.0	0.4	0.4	0.2	0.2
0.2 gm	1.0	1.2	2.2	1.0	1.0	0.6	1.0	0	0	0	0	0
TORDON 10K PELLETS SPOTTED												
0.4 gm	0.2	0.8	1.2	1.2	0.4	1.0	1.2	1.2	0.8	0.6	0.4	0.4
0.2 gm	1.0	1.0	0.8	1.0	0.8	0	0	0.2	0	0	0	0

* n = 5 plants/test

Plant response category:

0 = healthy, no effect
1 = light effects, chlorosis < 50X of plant
2 = chlorosis > 50% of plant
3 = moderate effects, > 50% leaf desiccation/defoliation
4 = 50-75% leaf desiccation/defoliation
5 = 75-90% plant death (cambium, stem desiccation)
6 = 90-100% plant death

similar to those observed on ROUNDUP-treated Russian olive and Florida blackberry. Light chlorosis occurred in the remaining 2 plots, and this persisted until the sixth month, when all growth appeared normal and healthy. None of the remaining treatments produced any observable effects on R. ellipticus.

Cut-Stump Treatments. The most effective of the cut-stump treatments on yellow raspberry was the 20% concentration of TORDON 22K in water (Table 12). This resulted in an 80% mortality rate (4 of 5 stumps died with no shoot or root resprouting) at one year. Cambium vigor evaluations at 7 months indicated complete mortality of all 5 stumps. In addition, no resprouting was observed on any of the decaying stumps during the next 5 months. By the twelfth month, however, resprouting was observed 15 cm from one stump from roots which had apparently survived the treatment. Leaves which appeared on the 2 resprouts were deformed, with leaf margins curling upward towards the midrib. In addition, the upper leaf surface was bronze in color, and the shoots appeared stunted. It is not known at this time if these deformities are permanent or whether the stump will subsequently produce healthy growth. Data obtained from herbicide tests on another Rubus species (R. arautus in this report) suggest that the longer the resprouts survive, the greater the likelihood of a resumption of normal growth.

Four treatments, TORDON RTU, 20% GARLON 4 in diesel oil, undiluted GARLON 4, and undiluted TORDON 22K, resulted in a 60% mortality of treated stumps. Cambium vigor evaluations of the stumps treated with undiluted GARLON 4 at 7 months indicated complete death of all 5 stumps. However, in the eleventh month, one healthy root resprout was observed 5 cm from one stump, and by the twelfth month healthy resprouting was occurring 8 cm away from a second stump. Mortality rates of R. ellipticus were 40% or less for the remaining 4 treatments tested. Table 12 indicates that lower concentrations of TORDON 22X were more effective than the high concentration. It may be that the high concentrations caused rapid tissue death, which obstructed translocation of the herbicide to the root system.

Effects on Non-taraet Native Species

Cut-Stump Treatments. No adverse effects on any native plant species were observed within a 1-m radius of any of the test stumps. Non-target species included 'ohi'a, hapu'u pulu (Cibotium slaucum (J. Sm.) Hook. and Arn.), ama'u (Sadleria pallida Hook. and Arn. and S. cyatheoides Kaulf.), and 'olapa (Cheirodendron triqynum (Gaud.) Heller). Since it is unlikely that any of the species were exposed to the treatments, no conclusions can be drawn as to sensitivity to the herbicides.

Foliar Treatments. Two 'ohi'a trees and one hapu'u, each 2-3 m in height, were exposed to the 50% GARLON 4 spray. The hapu'u was growing within 1 m of one of the test plots, with a single frond hanging within the plot. This frond died within

Table 12. Response of Rubus ellipticus to cut-stump treatments, Hawaii Volcanoes National Park, 1985-86. (Numbers in table represent mean response categories.)

Treatment*	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	% DEAD STUMPS**
UNTREATED	4.4	0	0.2	0	0	0.2	0	0	0	0	0	0	0
TORDON RTU	5.0	5.0	5.0	4.6	4.6	4.2	4.2	3.6	3.6	3.4	2.8	3.0	60
ROUNDUP 100%	5.0	4.0	3.2	3.4	3.6	4.4	3.0	2.8	2.6	2.8	3.6	3.0	40
GARLON 4													
100%	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.2	3.6	60
2ox	5.0	4.6	4.4	4.0	4.0	4.2	3.8	3.6	3.4	3.4	3.4	3.4	60
5%	5.0	5.0	5.0	5.0	5.0	4.4	4.6	4.8	4.4	4.6	2.6	2.6	20
TORDON 22K													
100%	5.0	4.0	3.0	3.0	3.0	3.4	3.4	3.2	3.0	3.0	3.0	3.0	60
20%	5.0	4.8	4.4	4.6	4.6	4.4	5.0	5.0	5.0	5.0	5.0	4.4	80
5%	5.0	5.0	4.2	4.2	4.0	3.0	1.0	0.8	0	0	2.2	1.4	20
DIESEL OIL	5.0	3.8	3.8	3.2	2.6	2.2	1.6	1.8	1.4	1.4	1.4	1.4	20

* n = 5 plants/test

Plant response category:
- 0 = healthy, normal, resprouts
- 1 = healthy resprouts w/ light abnormalities (chlorosis)
- 2 = moderate resprouts w/ abnormalities
- 3 = light resprouts, w/ abnormalities
- 4 = no resprouts, cambium alive
- 5 = no resprouts, cambium dead.

** at one year post treatment.

3 months of treatment; however, the untreated fronds remained healthy and new fronds which appeared after treatment were healthy and normal. The 2 'ohi'a trees were growing within 2 of the GARLON 4 plots and were directly treated. Although the surrounding raspberry was heavily affected, both 'ohi'a trees remained healthy and normal and were apparently unaffected by the treatment.

Manasement and Research Recommendations

Both the cut-stump treatment of 20% TORDON 22K in water and the 50% GARLON 4 drizzle spray treatment were effective in controlling R. ellipticus. The cut-stump treatment is more target-specific than the drizzle spray, but it may involve clearing away considerable amounts of bramble in order to expose the stump for treatment. The difficulty of accessibility to the stem and the presence of native species in close association with yellow raspberry are the 2 major factors in determining treatment feasibility.

Further research is needed, including tests with enlarged sample sizes and larger plots, to more fully evaluate the ability of R. ellipticus to resprout from roots, even though the stump has apparently been killed. Effects on native species also need to be studied in a more systematic manner, so that hazards can be more fully understood. Monitoring should be sustained for several years, to give ample time for root resprouting and recovery. Treatments with other herbicides also need to be evaluated in an effort to effectively control R. ellipticus.

CUT-STUMP TREATMENTS FOR GLORYBUSH

MATERIALS AND METHODS

Two hundred twenty shoots of glorybush with basal diameters ranging from 1-13.5 cm were selected from a population in a wet 'ohi'a forest at 1,230 m elevation near the HAVO Visitor Center. Mean annual rainfall is 2,494 mm, and mean monthly maximum temperatures ranged between 19 C and 22 C, with the highest and lowest temperatures in August and February.

Lateral runners, which grow above and below ground on glorybush, made it necessary to trace each stem back to its primary root. Stems were then tagged, diameters measured, and plants were treated. Treatments consisted of severing the stems with a chainsaw at a maximum height of 15 cm and applying the herbicide immediately to ensure maximum uptake and translocation throughout the root system. On plants with basitonic branching, all stems were cut, treated, and monitored, but only the largest stem was measured.

The 11 treatments tested included: 5% and 20% solutions of GARLON 4 in diesel oil; TORDON RTU undiluted; 5% and 20% solutions of ROUNDUP, TORDON 22K, and AMITROL T in water; diesel oil only; and an untreated control. Treatments were applied on the fresh cut so as to cover the entire surface, especially the cambium. The treatment surface was cut as level as possible to reduce runoff prior to absorption of chemical by the stump. The distance between treated areas was as great as practical (usually > 3 m) to reduce the chances of cross contamination among connected glorybush roots. Treatments were applied to plants on January 10 and 11, 1985 under sunny and dry weather conditions. No rain fell for at least 4 hours after treatment on either date. Monitoring, conducted at monthly intervals for one year, consisted of visual observations of resprouting buds. The quantity of resprouting buds was rated in one of 3 categories: light (1-5 resprouts), medium (6-50 resprouts), and heavy (> 50 resprouts). Height of the tallest resprout was measured at each monitoring interval. Any abnormalities in resprouts were also noted (e.g. chlorosis, distortions).

RESULTS AND DISCUSSION

GARLON 4 in a 20% dilution with diesel oil was the most effective treatment tested, with 85% control of glorybush after one year (Table 13). A cambium vigor evaluation conducted on the non-resprouting stumps at one year indicated complete death of all stumps. Resprouting on the surviving stumps was supressed until the seventh month. The resprouts were etiolated with chlorotic leaves. The deformities were short-lived, however, and by one year the resprouts appeared normal.

TORDON RTU and 20% TORDON 22R in water resulted in no resprouting and complete cambium mortality on 75% of treated stumps. The stumps which survived produced shoots with deformed leaves which were still evident at one year. Additionally, three 20% TORDON 22K-treated stumps produced initial resprouts which died but were subsequently followed by healthy sprouts. This same pattern of initial resprout mortality was also observed among individuals in all of the other treatments, including the untreated control. Although there were some abnormalities in some of the remaining treatments (notably the extreme chlorosis which initially followed the AMITROL T-treated stumps), none of the other treatments effectively controlled glorybush.

EF ON NON-TARGET NATI SI ES

None of the native species present within a l-m radius of treated stumps exhibited any adverse reactions to the herbicides. However, during treatment application no non-target species were directly treated either accidentally or incidentally. Species monitored were: pukiawe, 'ohelo or kau-la'ai (*Vaccinium reticulatum* Smith), 'ohi'a, wawae'iole, 'uluhe (*Dicranopteris emarginata* (Brack.) W.J. Robins), and 'uki (*Machaerina angustifolia* (Gaud.) Royama).

IE AND RESEARCH RECOMMENDATIONS

Cut-stump treatment is a practical, cost-effective, highly specific treatment method which is well suited for both

Table 13. Percentages of glorybush (*Tibouchina urvilleana*) which resprouted after cut-stump treatment at Hawaii Volcanoes National Park, 1985-86.

Treatment*	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN
DIESEL OIL	10	30	20	30	45	45	55	40	60	60	60	60
GARLON 4												
20%	0	0	0	0	0	0	10	5	10	10	10	15
5%	0	0	5	0	25	20	30	25	40	40	40	45
ROUNDUP												
20%	0	10	45	45	75	100	100	95	95	95	95	95
5%	5	30	75	90	100	100	95	100	100	95	100	95
TORDON 22K												
2ox	0	0	0	5	10	15	20	10	20	25	30	25
5%	0	0	5	0	15	25	40	35	50	55	50	55
TORDON RTU	0	0	0	0	0	0	5	5	20	20	20	25
AMITROL T												
20%	10	45	65	80	90	95	100	95	100	95	95	95
5%	15	60	75	85	95	95	95	85	95	95	95	95
UNTREATED	15	55	85	95	90	95	90	95	95	95	95	95

* n = 20 stumps/treatment

the growth habit of glorybush and for the forest type in which it is currently found. GARLON 4 at 20% in diesel oil produced a high mortality rate with no adverse effects on native species. Retreatment is strongly recommended to achieve eventual eradication, and follow-up monitoring is necessary. Results of these tests indicate that further testing of higher concentrations of both GARLON 4 and TORDON 22K might result in a more effective treatment for glorybush, and therefore require less €allow-up monitoring.

SUMMARY

Effective herbicide control methods were found for all 7 species of alien plants of concern in this study. Kahili ginger was controlled to 100% rhizome death after one year with Maujet treatments of TORDON 22K and AMITROL T, and with surface broadcast treatment of TORDON 10K pellets at a 4-kg ae/ha (40#/acre) rate. Site-by-site evaluation for surface runoff potential, rare plant presence, expected residual activity, and cost-benefit ratios can be used by managers to determine which method to use for ginger control. However, additional tests over larger areas, with different densities of ginger and native plants, and longer monitoring, especially with use of AMITROL T, are recommended. More effort to determine residual activity and effects of picloram on microfauna is also needed.

Russian olive shrubs were most effectively controlled with TORDON RTU and 100% GARLON 4 in cut-stump treatments (to 100% cambium death and no resprouting after one year). Since TORDON RTU is less expensive on a per use basis and less hazardous to the operator than 100% GARLON 4, it is the preferred treatment. The specificity of application results in negligible effects to non-target plants. GARLON 4 at a 5% concentration in water is an effective foliar spray for Russian olive shrubs (complete cambium death at 1 yr) and seedlings. However, application risks to non-target plants and operators, especially when plants are greater than 1 m in height, makes this method less than optimum in many situations, More research on effective GARLON 4 concentration levels and non-target hazards is needed.

Overlapping frill-cut treatments for Grevillea banksii with 2.5, 5, and 10% GARLON 4 in diesel oil and 5 and 20% concentrations of TORDON 22K in water resulted in 100% mortality within 11 months. Younger trees were more susceptible and declined more rapidly than larger trees. GARLON 4 also resulted in 100% mortality of G. robusta, but TORDON 22K was not as effective as on G. banksii. The recommended treatment for both species of silky oak is 2.5% GARLON 4 in diesel oil, since cost and hazards to operator are lowest. No effects on native species were noted with this specific treatment.

The foliar applications of herbicides tested against blackberry were not completely effective in terms of vigor reduction of surviving plants, but conventional spraying with 2% ROUNDUP in water reduced plant cover more than any other treatment (to 10% or less in 4 of 5 plots), Although regeneration of native plants may be enhanced through blackberry cover reduction, effects of spray drift on non-target grasses and other plants and hazards to the operator must be considered in operational programs. Season of spraying must also be considered, to avoid fruit-bearing bushes sought by berry pickers. Retreatment regimes for blackberry should be evaluated and treated areas monitored for colonization and reinvasion for longer periods than they have been to date.

Only the 50% GARLON 4 drizzle application proved effective in controlling yellow raspberry (75-90% plant Ueath), of the 7 foliar and soil treatments applied. A concentration of 20% TORDON 22K in water, applied as a cut-stump treatment, produced 80% mortality. Choice of treatment depends upon density of bramble and native species vulnerability. Further knowledge is needed about the effects of other herbicides and concentrations; the effects of drizzle applications of GARLON 4 on native species; and the resprouting capabilities of yellow raspberry.

Control of glorybush with a 20% dilution of GARLON 4 in diesel oil as a cut-stump treatment resulted in cambium death of 85% of the plants after one year. The treatment is practical, cost effective, and highly specific; no effects on native species were observed. More information is needed about retreatment with GARLON 4, compared with one-time use of higher concentrations of GARLON 4 and higher than 20% concentrations of TORDON 22K.

An important cautionary note emerged from the Russian olive tests. Field observations conducted 2 years post treatment in the cut-stump test revealed resprouting on one TORDON RTU-treated stump. A single root resprout, located 10 cm from the treated stump, was apparently healthy and normal. Yet, cambium vigor checks on this stump at one year had indicated no viable tissue on any portion of the stump, Long-term monitoring, especially when dealing with alien tree or shrub species, is important.

The current restrictions on operational use of TORDON in Hawai'i, and the expected withdrawal from the market of all TORDON products by Dow Chemical Company in the near future, make it necessary to reevaluate the status of knowledge about control of alien plants treated in this study and also that for other species. For example, without TORDON, effective treatments for kahili ginger and yellow raspberry are compromised wholly or in part. Testing of a wider variety of chemicals thus seems a necessity to ensure availability of effective chemicals. Chemicals which are less persistent than

TORDON are known to be available. Along with this approach, determination of retreatment intervals and effective concentrations (and even sequences) of less persistent chemicals to be used in retreatment seems desirable. More information on hazards to native species is needed for some application techniques in certain areas, and for many species. Especially important is the testing of herbicides in near-native systems such as HAVO's Special Ecological Areas (SEAs). Most tests to date have been conducted in areas with heavy concentrations of alien plants. Obviously, less herbicide per unit area is necessary in more pristine areas, but encounters with native species increase in these areas.

The use of herbicides on additional alien plant species which threaten the intactness of native ecosystems should be studied. A few examples of such species are banana poka (Passiflora mollissima (HBK) Bailey); Paspalum spp.; pearl flower (Heterocentron subtriplinervium (Link and Otto) A. Br. and Bouche); molassesgrass (Melinus minutiflora Beauv.); Jerusalem cherry (Solanum pseudocapsicum L.); and meadow ricegrass (Microlaena stipoides (Labill.) R. Br.). Concurrent information on the effects of herbicide treatment for these species on native plants is needed.

Better information on the persistence of herbicides in soils, the colonization of treated areas by alien and native plants, and the costs of herbicide applications by different techniques in different situations is also needed. Information on the effects of herbicide treatments on invertebrates and birds, in particular, is necessary in more intact ecosystems. Close monitoring of operational usage of chemicals in native systems should be a key element in a management-oriented herbicide research program in a public agency.

We believe that herbicides can be one effective tool in restoration of Hawaiian ecosystems. However, much more remains to be learned. A continued modest investment in research on and monitoring of herbicide use should ensure responsible integration of this important approach with other approaches used in ecosystem restoration programs in Hawai'i.

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APPENDIX A

ALIEN PLANT SPECIES USED FOR HERBICIDE TESTING (KAHILI GINGER IS NOT SHOWN)

Russian olive (Linociera ligustrina) 3 m high growing at the base of an 'ohi'a tree in the Ainahou Area of Hawaii Volcanoes National Park. (D. Kageler photo)

A young silky *oak* (Grevillea robusta) tree 5 m tall *growing* in an open scrub 'ohi'a forest outside the western boundary of Hawaii Volcanoes National Bark.

A mature scarlet silky oak (Grevillea banksii) 4 m tall in an *open* scrub 'ohi'a forest outside the western boundary of Hawaii Volcanoes National Bark.

Yellow raspberry (<u>Rubus</u> <u>ellipticus</u>) growing on a road cut through a closed-canopy wet koa/'ohi'a/tree fern forest in the Ola'a Tract of Hawaii Volcanoes National Park. This individual is 2 m in height and is beginning to displace native vegetation. (D. Kageler photo)

Blackberry (Rubus argutus) showing leaves (center), flowers (lower right), and fruit (upper left). (NPS photo)

Close-up of glorybush (Tibouchina urvilleana) showing leaves and flowers. (D. Kageler photo)

APPENDIX B

TECHNIQUE USED FOR MAUJET TREATMENT OF KAHILI GINGER AND FRILL-CUT TREATMENT OF SILKY OAK

Rhizomes of kahili ginger (Hedychium gardnerianum) are denuded of vegetation prior to herbicide treatment using the Maujet micro-injection system. An 11/64-in hole is drilled 3/8 in deep into the rhizome. A plastic feeder tube is inserted into the hole. (D. Kageler photo)

Vise-grip pliers are used to hold the tube at the proper depth. (D. Kageler photo)

An inverted herbicide-filled capsule is inserted onto the tube using a rubber mallet. (D. Kageler photo)

The *capsule* is then rotated to an upright position so herbicide drains into the rhizome, (D, Kageler photo)

close-up of the continuous-frill technique, with cuts made by hatchet. Herbicide is squirted into the cut. (D. Kageler photo)

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